ROLE OF CERTAIN NATURAL FACTORS IN THE FORMATION OF SNOW AVALANCHES

by

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SOURCE: TRUDY NOVOSIBIRSKOGO INSTITUTA INZHENEROV ZHELEZNODOROZHNOGO TRANSPORTA, VOPROSY PROYEKTIROVANIYA I STROITEL'STVA ZHELEZNYKH DOROG (Works of the Novosibirsk Institute of Railroad Transportation Engineers, Problems of Planning, Designing and Building Railroads)
Issue No. 76
1968
pp 81-87

17

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1. REPORT IDENTIFYING INFORMATION

A. ORIGINATING AGENCY: U. S. Army Cold Regions Research and Engineering Laboratory Hanover, New Hampshire 03755

B. REPORT TITLE AND/OR NUMBER: Role of Certain Natural Factors in the Formation of Snow Avalanches by Yu. A. Marin (~~CRREL TL~~ 226)

C. MONITOR REPORT NUMBER

D. PREPARED UNDER CONTRACT NUMBER(S)

2. DISTRIBUTION STATEMENT This document has been approved for public release and sale; its distribution is unlimited.

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ROLE OF CERTAIN NATURAL FACTORS IN THE FORMATION OF SNOW AVALANCHES

Trudy Novosibirskogo Instituta Inzhenerov Zheleznodorozhnogo Transporta, Voprosy Proyektirovaniya i Stroitel'stva Zheleznykh Dorog (Works of the Novosibirsk Institute of Railroad Transportation Engineers, Problems of Planning, Designing and Building Railroads) No 76, 1968, Pages 81-87

Yu. A. Marin

Considering the effect of meteorological and other natural conditions the characteristics of which have already been accumulated at the present time becomes entirely necessary in the practice of planning, designing, building and operating engineering structures. In particular, problems connected with the effect of atmospheric conditions have defining significance for railroad building in mountainous and taiga terrain and also for successful protection of the operated railroads from snow avalanches. From this comes the necessity of investigating the effect of meteorological conditions considering the relief and afforestation of the area on the occurrence of avalanches. In this article an effort is made to establish at least approximately the effect of air temperature, amount of precipitation, the wind rose diagram and the snow transport connected with it on the formation of snow avalanches in one section of the Kuybyshev Railroad.

The investigated section of the road is at the southwestern extremity of the Karatau Ridge. The snow crumbles to the left as the distance measured in kilometers increases. Located on the narrow right bank terrace of the S. River, the dirt roadbed has fallen in places into the river channel. The steep (up to 55-70 degrees), although low (on the order of 100-150 meters) cliffs run along a comparatively short section of 28 km in which 12 avalanche areas are counted. The total extent of the avalanching is 3,520 meters or approximately 10 percent of the length of the cliff section of the railroad.

The sizes of the avalanches are presented in Table 1. This table also includes numerous, but small snow avalanches after individual snow falls occurring annually. The magnitude of each such avalanche is defined approximately as 80-150 m^3.

The 27-28 kilometer section is the most dangerous. Here, the right bank floodplain terrace runs along a narrow strip at the foot of a steep cliff of a mountain ridge broken in places. The difference in rail head marks and the highest points of the cliff is 144 meters. The surface of the cliff is uneven -- it abounds in hanging benches and individual promontories, and it is broken by shallow, short hanging ravines in places. There is no vegetation on the cliff.

Under the conditions of the prevailing southwesterly and southerly winds, the ravines are snow collecting basins.

The remaining sections at 29, 32, 36, 37, 38, 42, 43, 50, 52, 53, 54 and 55 kilometers have cliffs covered with sparse underbrush and shrubs.

The windward slope at 27-28 kilometers is bare of any vegetation at the present time. The forest on the back slope was cut down in the

Table 1.

Date	km, running kilometer	Avalanche dimensions Length (m)	Width (m)	Height mean (m)	Volume (m^3)	Remarks
11 Jan 1951	27	11	15	3	500	
22 Nov 1951	35	13	18	3.6	850	
3 Dec 1951	27, 4 ravine	27	12	1.5*	500	The asterisk denotes the height of the avalanche or the height of the snow with respect to the entire width of the upper base of the dirt roadbed.
12 Dec 1952	27, 1 ravine	11	15	2	345	
8 Dec 1952	31	17	12	2	420	
17 Dec 1953	27	7	15	2.5*	500	
8-9 Feb 1958	27	14	12	1.5	250	
15 Feb 1960	41, run. k 6	25	15	2	750	
15 Feb 1960	41, run. k 6	36	15	3	1620	
15 Feb 1960	41/42	33	16	4*	2112	
15 Feb 1960	42, run. k 1	35	15	3	1575	
15 Feb 1960	43, run. k 1-2	40	20	4*	3200	
15 Feb 1960	43, run. k 2	50	12	3	1800	

1920's 1 , and it is characteristic that the occurrence of masses of snow falling systematically on the tracks began in the thirties.

Undoubtedly, the forest promoted accumulation of snow on the back slope part of which subsequently was not in the position to cause avalanching although it fell in the ravine.

Now the surface of the back slope remains entirely bare in the winter at the same time as the snow cover in the valley reaches 0.8 - 1.1 meters. In years of abundant snowfall, a large quantity of snow accumulates

Table 1

Key: a. year

b. month, date

c. km, running kilometer

d. avalanche dimensions

e. length, meters

f. width, meters

g. height (mean), meters

h. volume, m^3

i. remarks

j. The asterisk denotes the height of the avalanche or the height of the snow with respect to the entire width of the upper base of the dirt roadbed.

k. ravine

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Now the surface of the back slope remains entirely bare in the winter at the same time as the snow cover in the valley reaches 0.8-1.1 meters. In years of abundant snowfall, a large quantity of snow accumulates in the ravines the mass of which loses stability and rushes downward, sometimes entraining small pieces of base rock, and it inundates the railroad track.

In Table 2 we have some information about avalanches in a 28 km section for 15 years. Inasmuch as no systematic observations have been made in the investigated section, the data were taken partially from track section documents reported in part by senior hydrometeorologist of the Kuybyshev Railroad Division A.G. Khayrullin.

Table 2.

Date	Location of avalanche (kilometers of track)	Remarks
11 Mar 1951	27,28,35	In 1956-1959, small snow avalanches were noted after abundant snowfalls. There are no data for 1953, 1954, 1961-1963.
22 Dec 1951	27,28	
8 Dec 1952	32	
11 Nov 1953	27,28	
1956	27,52	
1957	27,28	
1958	27,28	
1959	27,28,32,52	
15 Feb 1960	27,28,32,42,43	
16 Feb 1960	37	
18 Feb 1960	32,42,43	
2 Feb 1964	28,50,52	
2 Feb 1965	32,37,38,28,30	
24 Feb 1966	32,28	

The maximum size of the avalanches belongs to November and December, February and March. In an especially snowy winter, there are 25-30 avalanches in the ravines the mass of which loses stability and rushes downward, sometimes entraining small pieces of base rock, and it inundates the railroad track.

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Table 2

Key:
a. year
b. date, month
c. location of avalanche (kilometers of track)
d. remarks
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The maximum size of the avalanches belongs to November and December, February and March. In an especially snowy winter, there are 25-30 avalanches differing with respect to volume and degree of danger to train traffic (track section data).

On the basis of the data of the Ufa weather station and individual information about wind conditions obtained at the M weather station and also analysis of monthly and annual wind rose diagrams for winter from 1956 to 1966 according to the K and U weather stations, the prevailing wind directions have been established as southwesterly and west-southwesterly (Figure 1).

According to the data of weather station K, the maximum number of days with a general snow storm in 1940-1966 was from 21 to 23 per month. The mean duration of general snow storms is presented in Table 3 for the winters of 1940-1960.

The duration of the snow storms in the investigated part of the Western Urals indicates the snow storm nature of accumulation of snow masses in the ravines and on the slopes.

The maximum annual total of days with solid precipitation varies in the winters with the most snow from 24 to 34. This is from 15 to 26 percent of the total length of the winter. The number of days with solid precipitation of 2 mm and more for each of the 29 winters according to weather station K is presented in Figure 2.

The maximum ten-day depth of the snow cover taken over a 30-year period does not, on the average, exceed 80 cm, reaching 120 or 130 cm in individual cases (Figure 2).

The graph was compiled by the data of weather station U for which the greatest depth of the snow cover on the last day of the ten-day period was noticeably more than at weather station K.

Table 3.

Weather station	Mean duration of snowstorms in hours by months							Avg total hours for the winter	No. of winters
	O	N	D	J	F	M	A		
K	32	75	90	81	58	94	18	458	20

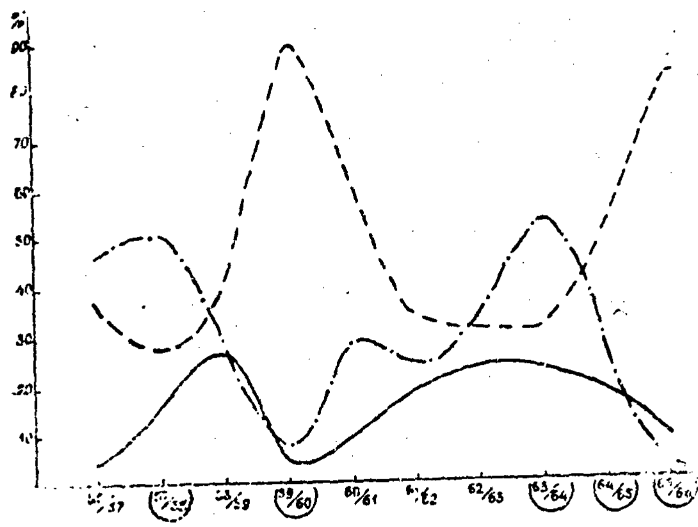

Figure 1. Frequency of wind directions for the winters of 1956-1966: ---- SSW; —.—.— S; ____ SW.
Note: The circles denote the winters with most frequent and severe avalanches.

In the winters of 1957/58, 1959/60, 1963/64, 1964/65 and 1965/66 with the most avalanches, the depth of the snow cover does not always approach the maximum, but it always remains above average.

The fact that during the prolonged snow storm period the brigade of rock climbers was forced to cut away the blown up snow barriers every

Table 3

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a

Key: a. weather station

b. mean duration of snow storms in hours by months

c. total for the winter (on the average), hours

d. number of winters

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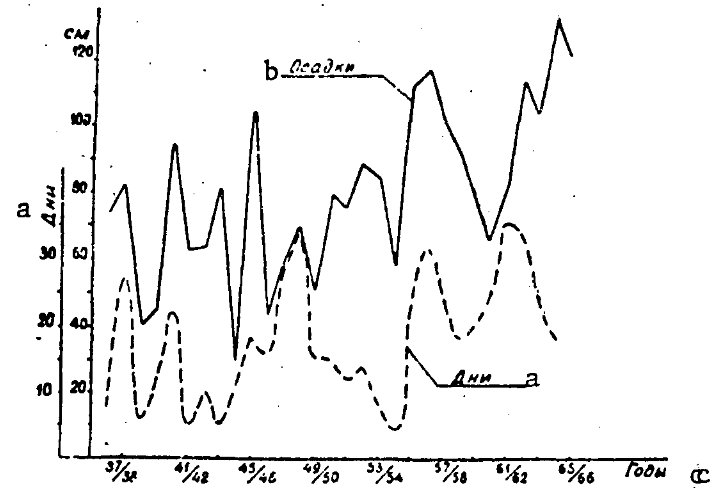

Figure 2. Number of days with solid precipitation and maximum depth of the snow cover for 30 years.

Key: a. days

b. precipitation

c. years

two hours around the clock to prevent spontaneous slides also indicates the accumulation of snow in the ravines as a result of snowdrift transport [1].

In order to prevent accumulation of snow in the ravines as a result of snowdrift transport, at the end of the 1930's a stationary snow protection fence was installed on the back slope of the avalanche section at 27 km. According to the data of B. P. Bozhevol'nov and N. S. Kradinov, it held back no less than 150 m^3 of snow per running meter of length for the winter.

In addition, the volumes of snow transport were calculated for the winters from 1956 to 1966 according to the data of the nearest weather stations U and K. By the discharge procedure [2] (Table 4):

$$W_n = \frac{0.774 \cdot 10^{-4}}{\gamma_s} \sum_{i=1}^{n} \sum_{a=1}^{m} V_{\phi a}{}^3 \sin x \cdot t_a \ m^3/n \ m.$$

Key [throughout article]: a. $V_{\text{wind vane}}$

where $V_{\text{wind vane}}$ is the wind vane wind velocity;

α is the angle between the direction of the ridge and the direction of the driven snow;

t_t is duration of the snow storm;

γ_s is the density of the drift taken as 0.4 tons/m^3 (with a depth of deposition to 3 meters).

The snow density which the authors give for various conditions and for different depth of deposition is in the given case close to the measurement results on the 27 km cliffs by the Ufa branch of the geophysical station in February 1960. The density is 0.384 tons/m^3. Considering that the depth of the snow in ravines exceeds 3 meters, it is entirely permissible to round the snow density to 0.4 tons/m^3.

Table 4.

Weather station	1956/57	1957/58	1958/59	1959/60	1960/61	1961/62	1962/63	1963/64	1964/65	1965/66	Avg
	Snow transport, m^3/running meter										
U	52.47	69.80	25.83	23.21	16.11	12.31	26.35	14.35	14.64	13.53	25.3
K	170.72	181.13	135.69	142.09	130.55	122.49	217.36	135.09	117.61	117.75	147.06

Table 4 permits us to draw the following conclusions:

1. The maximum and minimum volumes of snow transport for each weather station coincides by years, but they are equal with respect to magnitude.

2. The actual magnitudes of the snow transport volumes which can be obtained by many years or even two or three summers of field observations are in the range of values obtained.

It is noted that when little snow is accumulated in the ravines, the short snow storms of the southerwesterly points of the compass cannot cause snow avalanches on the tracks. However, if the snow storm winds in these directions blow for more than 12 hours, the capacity of the snow collecting basins turns out to be insufficient to hold back the snow deposited in them to say nothing of long storms lasting more than 2 days. It is possible therefore that avalanching occurs in the given region, as a rule, either during the storm or immediately after it is over. The avalanches can be considered as "Khibinskiy type" (the G. K. Tushinskiy classification) [3]. According to the genetic classification of V. N. Akkuratov they are defined as snow storm avalanches.

The graph of the variation of accumulation of precipitation (variation in depth of the snow cover) for the winters of 1957/58, 1959/60, 1963/64, 1964/65 and 1965/66, when the largest avalanches occurred (see Figure 2), permits us to see that the volume of crumbled masses of snow sometimes reaches 12,00 m^3, but it usually does not exceed 500 m^3.

The possibility of the snow sliding from the remaining slopes and ravines, except for the 27-28 kilometer section, basically depends on the amount of solid precipitation for the winter. This is indicated by the data by years (Table 5).

The slopes of the mountain massif in this kilometer section have different steepness (from 40 to 60 degrees); they are in the majority of cases covered with medium dense underbrush and shrubs in which open strips are easy to see in the winter in the avalanche locations. Here, snow drift transport of the snow drops out as the basic prerequisite for the formation of avalanches, giving way to accumulation of snow on the slopes as a result of snowfalls. The variations in diurnal temperatures lead to an intense process of recrystallization and development of deep hoarfrost, and this in turn, leads to avalanching. In the winters with the most snow, (for example, the winter of 1964/1965) the avalanches occurred in a large portion of all the avalanche locations where snowdrift transport either was insignificant or impossible in view of the solid afforestation of the back slopes.

Table 5

a	b	c
1955/56	112	27,52
1956/57	122	27,28
1957/58	103	27.28
1962/63	114	No data
1963/64	103	28,52,50
1964/65	132	32,37,42,43, 28,38,36
1965/66	120	28,32

Key: a. years; b. depth of snow cover, cm; c. location of avalanches (kilometers of track); d. no data

Thus, the existing, incomplete observation data for avalanches, meteorological data for the last ten years and the analysis of avalanche formation causes in the investigated section performed on the basis of these data permit us to draw the following conclusions.

1. The basic factors determining avalanching can be considered to be the following: a) falling of solid precipitation close to normal or above it; b) snowdrift transport; c) sharp warming; d) overloading of the slope with freshly fallen or snow storm snow.

2. The volumes of the avalanches are relatively small.

3. The avalanche period continues from November to March where the majority of avalanches occur in December, February and March.

4. The thickly forested slopes with steepness up to 50 degrees are safe for uninterrupted operation of the railroads passing along their feet, but with the slightest disturbance of integrity of the forest mass (clearing the right of way for electric power lines and communication lines, cutting location surveying markers on the slopes) it is impossible to guarantee this safety.

Crossing of mountainous regions by operating railroads is realized in many cases without considering the avalanche nature of the terrain. This leads to additional expenditures. Thus, according to the Kuybyshev Railroad Section data, the expenditures on snow removal from the tracks as a result of snow slides amounts to 125,000 rubles per year per kilometer of track without considering the losses connected with shutting down the run and damage to certain transport devices. Therefore, during the process of exploring new roads under mountainous conditions and when planning and designing protective measures on the existing roads, it is necessary to provide for careful winter observations of potential avalanche slopes at the foot of which the track will be laid and to study the physical-mechanical properties of the snow, use the data of the nearest weather station and at least perform minimum meteorological observations of factors causing avalanching (wind velocity and direction, volume of snow transport, magnitude of precipitation, temperature) directly in the avalanche zone.

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